Received: 20 August 2020 | Revised: 25 March 2021 | Accepted: 24 May 2021

DOI: 10.1002/ajpa.24343

RESEARCH ARTICLE

American Journal of PHYSICAL ANTHROPOLOGY WILEY

Beyond faith: Biomolecular evidence for changing urban economies in multi-faith medieval Portugal

Alice Toso[1,2] | Simona Schifano[1] | Charlotte Oxborough[1] | Krista McGrath[1,2] | Luke Spindler[1] | Anabela Castro[3,4] | Lucy Evangelista[5,6] | Vanessa Filipe[7,8] | Maria João Gonçalves[9] | Antonio Marques[10] | Inês Mendes da Silva[5] | Raquel Santos[11] | Maria João Valente[12] | Iona McCleery[13] | Michelle Alexander[1]

[1]BioArCh, Department of Archaeology, University of York, York, UK

[2]Department of Prehistory & ICTA, Autonomous University of Barcelona, Barcelona, Spain

[3]Departamento de Antropologia, Instituto Superior de Ciências Sociais e Políticas, University of Lisbon, Lisbon, Portugal

[4]Uniarq - Centro de Arqueologia, University of Lisbon, Lisbon, Portugal

[5]Era Arqueologia SA Lisbon, Lisbon, Portugal

[6]University of Algarve, Interdisciplinary Center for Archaeology and Evolution of Human Behaviour (ICArEHB), Faro, Portugal

[7]Cota 80.86.Lda, Lisbon, Portugal

[8]IAP, Instituto de Arqueologia e Paleociência, FCSH, Nova University of Lisbon, Lisbon, Portugal

[9]Museu de Arqueologia de Silves, Silves, Portugal

[10]CAL – Centro de Arqueologia de Lisboa, Câmara Municipal de Lisboa, Lisbon, Portugal

[11]Neoepica Lda, Lisbon, Portugal

[12]FCHS, CEAACP – Centro de Estudos de Arqueologia, Artes e Ciências do Património, University of Algarve, Faro, Portugal

[13]School of History/Institute for Medieval Studies, University of Leeds, Leeds, UK

Correspondence
Institute of Environmental Science and Technology (ICTA) ICTA-ICP, Edifici Z, Carrer de les columns Universitat Autònoma de Barcelona 08193 Bellaterra, Barcelona, Spain
Email: alice.toso@uab.cat

Funding information
Archaeological Institute of America, Grant/Award Number: Archaeology of Portugal Fellowship; Arts and Humanities Research Council; Banco Santander, Grant/Award Number: Santander International Connection award 2014; Barakat Trust, Grant/Award Number: Barakat Trust Award 2015; BioArCh, Department of Archaeology, University of York

Abstract

Objectives: During the Middle Ages, Portugal witnessed unprecedented socioeconomic and religious changes under transitioning religious political rule. The implications of changing ruling powers for urban food systems and individual diets in medieval Portugal is poorly understood. This study aimed to elucidate the dietary impact of the Islamic and Christian conquests.

Materials and Methods: Radiocarbon dating, peptide mass fingerprinting (ZooMS) and stable isotope analysis ($\delta^{13}C$, $\delta^{15}N$) of animal ($n = 59$) and human skeletal remains ($n = 205$) from Muslim and Christian burials were used to characterize the diet of a large historical sample from Portugal. A Bayesian stable isotope mixing model (BSIMM) was used to estimate the contribution of marine protein to human diet.

Results: Early medieval (8–12th century), preconquest urban Muslim populations had mean (±1*SD*) values of -18.8 ± 0.4 ‰ for $\delta^{13}C$ 10.4 ± 1 ‰ for $\delta^{15}N$, indicating a predominantly terrestrial diet, while late medieval (12–14th century) postconquest Muslim and Christian populations showed a greater reliance on marine resources with mean (±1*SD*) values of -17.9 ± 1.3‰ for $\delta^{13}C$ and 11.1 ± 1.1‰ for $\delta^{15}N$. BSIMM estimation supported a significant increase in the contribution of marine resources to human diet.

Discussion: The results provide the first biomolecular evidence for a dietary revolution that is not evidenced in contemporaneous historical accounts. We find that society transitioned from a largely agro-pastoral economy under Islamic rule to one characterized by a new focus on marine resources under later Christian rule. This economic change led to the naissance of the marine economy that went on to characterize the early-modern period in Portugal and its global expansion.

KEYWORDS
bioarchaeology, fishing, medieval, paleodiet, Portugal

1 | INTRODUCTION

The application of biomolecular archeology in the Iberian Peninsula has enriched our understanding of one of the first multi-faith and multi-cultural societies in medieval Europe. Recent studies reveal a complex picture of the eight centuries during which Muslims, Jews and Christians co-existed, characterized by diversified political settings, economic strategies, religious beliefs and population movements (Collins, 1994; Santos et al., 2014).

Between the 8th and 14th centuries, the Iberian Peninsula witnessed unprecedented structural, societal and religious changes following the Islamic conquest in 711 CE and the Christian conquest from the mid-12th century (Kennedy, 1996). Muslims ruled over much of the peninsula, creating a division between the northern Iberian Christian Kingdoms and the southern Islamic caliphate. During the early medieval period, historical sources indicate an economy based on agriculture and pastoralism throughout the Peninsula, while marine resources were exploited on a small scale, characterizing the subsistence strategies of coastal settlements (García-Sánchez, 1992). Archaeology and historical sources often reveal a gradual and continuous passage from one society to the other between the Muslim and the Christian period and although archeological evidence for destruction and abandonment levels have been identified; cultural practices continued in a more fluid way, sometimes facilitated by influential Mozarab (Christians living under Islamic rule) elites (Simões, 2012). The increasing number of isotopic studies on medieval populations, however, shows a composite picture of food practices with high dietary variability at the local level (Alexander et al., 2019; López-Costas & Müldner, 2018; Lubritto et al., 2017; MacKinnon et al., 2019). In the later medieval period, Christian Kingdoms of the north gradually pushed south and conquered Islamic territory (Kennedy, 1996) and by the mid-13th century, the Kingdom of Portugal lay under Christian rule. The expanding reach of the Kingdom of Portugal saw the creation of new trading routes to Northern Europe, the Americas and Africa, with an emphasis on seafaring activities (Amorim, 2009).

While much previous historical research has focused on the political and religious transitions in Iberian medieval society, research on their impact on individual diets has been limited. Aquatic resources became economically important food items during the late medieval and early modern periods in Portugal, however their relative contribution to diet is poorly understood and often subject to sweeping generalizations (Amorim, 2009). In the light of political and societal turmoil that characterized the medieval period, the extent to which different food sources contributed to the diet of different groups, before and after the Christian conquest, also remain uncertain. It has been assumed that Northern European populations exploited marine and freshwater resources to sustain growing populations during this time period, although it is a matter of debate if this could be applied to southern Europe (Barrett et al., 2011). Remains of fish are scarcely recorded from archeological sites in Portugal, which may in part be due to recovery techniques and are therefore not sufficient to explore this issue alone. Stable carbon and nitrogen isotope analysis of bone collagen is a well-established technique to extrapolate dietary information from human, faunal and plant remains and has been employed to reconstruct medieval diets across the Iberian Peninsula (López-Costas & Alexander, 2019). However, the dietary practices of Islamic populations before and after the Christian conquest has rarely been explored (Alexander et al., 2015; Toso et al., 2019).

Here we report a novel contribution to disentangle diets in medieval Portugal, and specifically the importance of marine resources as a supply of dietary protein. New radiocarbon dates and a large body of bulk collagen stable isotopic (carbon and nitrogen) data from human and animal populations from three major urban sites: Lisbon, Beja and Silves have been produced. The relative contribution of terrestrial and marine resources to diet have been estimated using a Bayesian stable isotope mixing model (BSIMM, FRUITS) to provide a probabilistic model for the proportion of calories and protein derived particularly from marine resources.

1.1 | Archeological background and materials

Lisbon, Beja and Silves were three major urban settlements in medieval Portugal that played central roles in the economy during both Islamic and Christian rule (8–15th centuries) (Figure 1). All three cities

FIGURE 1 Distribution of the analyzed sites within the Iberian Peninsula. Full circles indicate the sites analyzed in this study, empty circles indicate comparative contemporary sites

were under Islamic control from 711 CE but were conquered by the Christians at different times between the mid-12th and mid-13th centuries (Marques, 1993). They are all situated on rivers, although Lisbon has closest access to the sea. At all three locations, pre- and post-Christian conquest burials of both Muslim and Christian individuals have been analyzed, serving a threefold purpose of elucidating food access and distribution in urban environments in relation to faith, economy and chronology. Potential sex related differences in diet were also considered.

Funerary practices in Medieval Iberia were varied. A number of different juridic texts highlight the variability of laws and their interpretation that regulated burial practices throughout the Islamic rule of the Iberian Peninsula (Fierro Bello, 2000). Despite regional variations, however, there is a broad consensus on the treatment of the dead during this period that includes the preparation of the corpse, the funeral and the preparation of the grave (Petersen, 2013). Muslim burials were usually placed in single graves oriented toward Mecca (SE orientation in Portugal) with the body lying on the right-side facing east and cemeteries themselves were commonly outside the city walls near one of the main gate of the city (Insoll, 1999). Early medieval Christian burial customs from other parts of the Iberian Peninsula were initially similar in placing cemeteries in the outskirts of the cities, however, after the Christian conquest, Christian parishes and their churches developed which provided burial space in their vicinity (Ruiz-Taboada, 2015). The typology of Christian graves varied in burial depth and could present the use of bricks, which were forbidden by Islamic law (Fierro Bello, 2000). Each tomb would include the remains of a single individual, as in the Islamic tradition, however the body was placed in a supine position with the head looking up. All tombs usually followed an east–west orientation. Due to these different practices and additional contextual information from historical and archeological sources, cemeteries are usually assigned to one of the three main religions that were practiced in Iberia at the time that is, Christianity, Islam, and Judaism, even when multiple cemeteries are found in relatively close proximity as in the case of Toledo (Ruiz-Taboada, 2015). Lisbon and Beja also provided rare evidence of multi-faith burial sites where Christians and Muslims were buried together; however, the contemporaneity of these burials was unclear.

In the following section the archeological background of the sites is presented including the sampled individuals. Additional details about the archeological background of the sites can be found in Data S1.

1.2 | Lisbon

In Lisbon, five archeological sites were sampled representing different chronologies: one site dates to the early medieval period (8–12th centuries) (Largo de Santa Marinha) while four sites (Largo das Olarias, Quarteirão dos Lagares, Poço do Borratem and Casa da Severa) date to the late medieval period (13–15th centuries).

In Largo de Santa Marinha, a total of eight rock-cut graves were identified following commercial archeological work, seven of which were primary Muslim burials located at the northern limit of the city's eastern Islamic cemetery. The burials were poorly preserved and only three individuals were analyzed from this site. No materials or grave goods were found in association with the individuals. The suggested chronology embraces the entire Islamic period in Lisbon (8–12th centuries) (Filipe et al., 2020).

The excavations in Largo das Olarias and Quarteirão dos Lagares took place at different times in the Mouraria neighborhood; however, they are likely part of the same Islamic cemetery of Lisbon and for this reason are grouped together here. Recent ongoing excavations that started in 2015 brought to light hundreds of burials and identified what is thought to be one of the main Islamic cemeteries of Lisbon. This recovery is significantly changing what was known of Lisbon under Islamic rule, since the only Muslim burials prior to this were recovered in the castle (Toso et al., 2019) and are not representative of the urban population because of their small sample size and peculiar location. The excavations at the site of Largo das Olarias are ongoing and therefore an in-depth study of the chronology, use and development of the site is underway. However, the complex stratigraphy of the site, and archeological finds such as coins and pottery, suggest a late chronology for the main part of the cemetery (13–15th century). A total of 22 Muslim and 15 Christian individuals were analyzed from these two sites.

Poço do Borratem is a Christian burial site located just outside the Mouraria walls connected to the nearby hermitage of São Matheus, erected between the 12th and 13th century. The burial site is believed to be located at the edges of the cemetery in close proximity to a street and the walls of the Mouraria, and for this reason, archeologists suggest that people buried there would have had a lower social status. The use of this space has been dated to the 14th and 15th centuries (Filipe et al., 2018). A group of 31 human individuals has been analyzed from this site as well as 13 faunal remains of similar chronology.

Finally, 22 faunal remains were sampled from an excavation that took place in a residential area at Casa da Severa. This site is located in the heart of the Mouraria, just over a 100 m from the Muslim cemetery of Largo das Olarias. The materials and the stratigraphic analysis from the excavation provided a chronology of use between the 12th and the 15th centuries (Valente & Marques, 2017).

1.3 | Beja

In Beja the only burial site analyzed was excavated at the Escola Secundaria Diogo Gouveia, where a total of 276 primary burials including 255 Muslims and 21 Christians were identified. Christian and Muslim burials were found in the same location with no segregation (Gomes et al., 2014) with a number of graves of different faith intercutting each other. Only one Christian individual was found with three bronze rings, but no other grave goods were found. Although the presence of a vast Islamic cemetery was known in this part of the city due to previous smaller commercial excavations, the stratigraphy of the site was unclear and did not help to ascertain if Muslim and Christian burials were contemporaneous or not. To ascertain the use of this space by the two different faith groups we undertook radiocarbon dating on two Muslim and three Christian individuals. Fourteen Christian and 41 Muslim individuals were isotopically analyzed from this site.

1.4 | Silves

In Silves three sites were analyzed: Rua 25 Abril of early medieval chronology, and Rua Miguel Bombarda and Largo da Sé dating to the late medieval period. Rua 25 Abril is a Muslim burial site and was the main cemetery in use under Islamic rule (Santos et al., 2008). Nearly 200 individuals have been recovered and one radiocarbon date from the older layers provided a date of 895–926 cal CE (Serra, 2012). A total of 26 Muslim burials were analyzed from this site. In Rua Miguel Bombarda a Christian cemetery has been identified, probably pertaining to the Ermida de Nossa Senhora dos Martires outside the city walls. Although the church is mentioned soon after the first Christian conquest of the city (1189–1191), the materials recovered during the excavation dated to the 13–14th centuries (Casimiro et al., 2008). A sample of 19 Christian individuals was analyzed from this site. Lastly, another Christian cemetery located at Largo da Sé was sampled ($n = 21$) and pertains to the Cathedral of Silves. Its construction started in the 13th century however it remained unfinished until the 15th century due to the situation of political instability (Gamito et al., 1997). Excavations suggest that this space was used as a burial site between the 13th and 15th centuries (Casimiro et al., 2008). Faunal remains ($n = 16$) were recovered at all sites and also from a small pit located in Rua A, in the vicinity of the Cathedral, associated with pottery dating between the 11th and 14th centuries. Because of the wide chronology they have been treated as one medieval baseline and used for both Muslim and Christian individuals from Silves.

1.5 | Diet in medieval Portugal

A detailed overview of the medieval diet in Portugal is provided in the Data S1, however dietary expectations are briefly outlined here. Throughout the medieval period, agriculture and farming were the central economic activities and provided the main food sources for the population at large (García-Sánchez, 1983, 1986, 1996). The south of Portugal did not grow much wheat and cereals were imported from the Maghreb and northern Africa during the Islamic and Christian periods (Constable, 1996) or from other regions in Portugal such as Entre-Douro-e-Minho, Beiras, Ribatejo and Estremadura during the late medieval period (Gonçalves, 1984). Among crops, wheat, a C_3 plant, was the most desirable, however secondary crops such as barley, rye and millet, a C_4 plant, were more affordable and provided food security when other resources were lacking (Catarino, 1998; Marques, 1987). The Muslim minority of Largo das Olarias living in Lisbon under Christian rule, or the lower status Christian population buried at Poço do Borratem could be likely candidates for the consumption of secondary crops as has been found in other low-status medieval Iberian populations (Alexander et al. 2019).

Livestock farming was also one of the most important economic activities through the Middle Ages in the Iberian Peninsula (Estaca-Gómez et al., 2018). During the Islamic period, the most common meats were lamb and mutton, followed by fowls and cow (García-Sánchez, 1986). Goat seems to be consumed more often in the Islamic period compared to the late medieval Christian period in Iberia (Waines, 1994). This trend is also confirmed by a number of zooarchaeological studies showing a preference for sheep/goat, followed by cow, chicken and rabbit during the Islamic period and a scarce presence of pig (Morales-Muñiz et al., 2011; García-García, 2017), while cattle, sheep/goat and pig are the most recovered species at Christian sites (Grau-Sologestoa, 2017). An important food source for the lower classes, would also be secondary animal products such as cheese, milk and eggs, however these cannot be discriminated from meat by their isotopic values.

Finally, marine resources have a distinctive trajectory in medieval Portugal. Arab authors have different opinions on whether fish was good for human consumption (García-Sánchez, 1986; Pellat et al., 2012). Fish and seafood recipes are scarce in medieval Andalusian cookbooks, although we expect small-scale coastal fishing could have been undertaken by lower classes to supplement their diet (García-Sánchez, 1983). Historical sources are more generous in information about the later Christian medieval period fishing practice and several species appear in city markets including the more expensive croaker, red porgy, red bream, and hake and freshwater catches such as salmon, lamprey and eel (Coelho, 1995) but also less expensive fish like sardines, sole and allis shad (Catarino, 1998; Martins, 2016). This trend could be associated with Christian abstinence from meat, however, economic ventures including contacts with the northern shores of the ocean led to the expansion of the fishing industry and brought Atlantic cod onto the table, which was salted (with salt from Aveiro and Viana do Castelo) or dried, to be preserved during the long journey back to Portugal (Azevedo, 1982; Cole, 1990). A virtual absence of fish remains from the majority of known medieval sites due to a lack of sufficient recovery techniques hinders a systematic assessment of the consumption of marine resources in Medieval Portugal. However, fish and mollusks have been recorded from Islamic Santarém (Davis, 2008), Silves (Davis, 2008) and Loulé (Branco & Valente, 2015).

2 | METHODS

2.1 | Sample selection

Specimens in this study were collected from three main urban sites dating to the Medieval period, both from the Islamic (8–12th century) and Christian (13–15th century) rule aiming at exploring faith and chronological changes in diet. Several sites in Lisbon, Beja and Silves were sampled to provide a representative sample of the population with equal numbers of male and female individuals whenever possible (Table 1). Only individuals that were classified as adult (over ~18 years of age) in the anthropological site reports were sampled. Further adult age groupings based on age-at-death estimations were not available.

Individuals were considered as Christian or Muslim according to their funerary practice which include a different position of the body, orientation as well as layout of the grave. In addition, historical and archeological sources collected in previous excavations were used to contextualize the burial sites. Assigning religious affiliation solely on the basis of burial practices can be misleading and problematic: a person could be buried following a rite but not have lived following the specific mandates of that religion and some of these cases include individuals that converted or were forced to convert throughout their lives (crypto Christians and crypto Muslims). Although the archeological and historical sources may seem a relatively limited way of identifying the potential complexities of religious affiliation (Christys, 2009), burial rite is unfortunately the only information we have on an individual's religious affiliation, and it has been commonly used by archeologists in Iberia to differentiate between religious groups. The individuals studied here followed the standard traditional rites described for these religious communities during this period in Iberia, however, since there is no certain way to assign religious affiliation, whenever we mention a Muslim or Christian burial, we are actually referring to individuals buried with a Muslim or Christian rite. Any incongruences for example, crypto Christians and crypto Muslims, would have probably been a rare occurrence in our dataset and is unlikely to have had a significant impact on our population study. Unfortunately, no mozarab (Christians under Muslim rule) burials were available for analysis and so the diets of these communities cannot be explored.

No indication of high social status could be inferred from historical sources or the rare instances of grave goods. Muslim burials rarely include grave goods and, in this study, only one individual from Quarteirão dos Lagares (QDL 104) was found with associated materials including three metal beads and the remains of a ring. A similar scarcity of grave goods characterizes the Christian burials. The only group of individuals with a certain higher status is the group excavated at São Jorge Castle (Toso et al., 2019). Faunal remains were chosen for preservation quality and from contexts of known chronological dates, preferentially from domestic deposits and as close as possible to the burials. In Lisbon and Silves, faunal remains are from contemporaneous pits excavated within domestic quarters, while no faunal remains were available in Beja and values of already published animal remains of late Roman chronology were used (Saragoça et al., 2016).

2.2 | Radiocarbon dating

The Western Atlantic coast of the Iberian Peninsula is influenced by a dynamic upwelling which strongly affects the fluctuations in the

TABLE 1 List of sampled individuals from each site with indication of sex estimation

	Site	Period	Faith	F	M	U	N
Lisbon	Largo de Santa Marinha	EM	Muslim	1	2	0	3
	Largo das Olarias	LM	Muslim	8	10	1	19
	Quarteirão dos Lagares	LM	Muslim	3	0	0	3
	Largo das Olarias	LM	Christian	10	5	0	15
	Poço do Borratem	LM	Christian	12	12	7	31
Beja	Escola Diogo Gouveia	EM	Muslim	21	19	1	41
	Escola Diogo Gouveia	LM	Christian	7	4	3	14
Silves	Rua 25 Abril	EM	Muslim	6	17	0	23
	Rua A	EM	Muslim	1	2	0	3
	Rua Miguel Bombarda	LM	Christian	13	6	0	19
	Largo da Sé	LM	Christian	9	12	0	21
Total				92	89	12	192

Abbreviations: CF, female; EM, early medieval; LM, late medieval; M, male; N, number of samples; U, undetermined sex.

TABLE 2 Radiocarbon dates for intercutting graves of Muslims and Christians at Beja. The methodology followed for calibration is provided in Data S1

Skeleton ID	Lab code	Faith	^{14}C yrs BP	Correction ΔR[a]	Marine %	Cal CE 2σ (95.4%)
BEJ 7278	28,461	M	1191 ± 23	95 ± 15	8 ± 4	776–966
BEJ 3207	28,464	M	973 ± 24	95 ± 15	3 ± 2	1021–1155
BEJ 3259	28,462	C	695 ± 24	95 ± 15	11 ± 5	1285–1394
BEJ 3083	28,463	C	651 ± 23	95 ± 15	12 ± 5	1303–1410
BEJ 3102	28,465	C	601 ± 21	95 ± 15	9 ± 5	1317–1425

Abbreviations: C, Christian; M, Muslim.
[a]Following [38].

ocean reservoir carbon offset on the western coast of Portugal (Soares & Dias, 2006). This marine phenomenon occurs in the open ocean and along coastlines, when deep water rises and replaces the surface water. The upwelling activity varies through time and research has shown that coastal values of ΔR in these regions may exhibit significant variability (Monge Soares & Martins, 2009; Soares & Dias, 2006). In the case of dynamic upwelling situations, the use and determination of a mean ΔR is considered to be meaningless and it is strongly suggested to use the determined ΔR value that is closer to the ^{14}C age to be calibrated (Monge Soares & Martins, 2009). In the case of this study, this corresponds to 800 to 1500 BCE. The recommended ΔR value for this period is 95 ± 15 (Monge Soares, 1993). Because the individuals herein presented a mixed diet with the inclusion of marine protein in their collagen (discussed below), the calibration considered the percentage of marine carbon to the diet in order to account for the marine reservoir effect. This percentage has been calculated with a BSIMM and is reported in Data S1 (Table S2) with the estimation obtained from a regression formula (Arneborg et al., 1999) for comparative purposes. BSIMMs estimation is much more conservative and produces lower values, however, this robust statistical approach was considered more reliable and was therefore used in this study. Uncalibrated ages were calibrated with OxCal 4.3 (Bronk Ramsey, 2008) with the IntCal13 (Reimer et al., 2013) calibration curve using the aquatic curve Marine13 (Reimer et al., 2013) and the regional reservoir offset (ΔR) reported above (Monge Soares et al., 2016).

2.3 | Peptide mass fingerprinting

Faunal remains whose species identification by macroscopic observation was hindered by fragmentation were analyzed with collagen peptide mass fingerprinting (ZooMS), largely resolving sheep/goat identifications. ZooMS was performed at the BioArCh lab facilities following a slightly modified methodology as described in (Buckley et al., 2010). In brief, a small sample (0.3–0.7 mg) of the collagen that had been extracted for isotope analysis was resuspended in 50 μl of 50 mM ammonium bicarbonate (Ambic, pH 8.0). 0.4 μg of trypsin was added and the samples were incubated at 37°C for approximately 18 h. Samples were acidified with 1 μl of 5% trifluoroacetic acid to stop the trypsin, and the collagen peptides were extracted using 100 μl C18 resin ZipTip® pipette tips (EMD Millipore). 1 μL of sample was spotted in triplicate onto a Bruker ground steel target plate along with 1 μl of α-cyano-hydroxycinnamic acid matrix and run, along with calibration standards, on a Bruker ultraflex III MALDI-ToF-MS. Resultant spectra were analyzed with mMass software (Strohalm et al., 2008) and the identifications made through comparison with a database of known species (Buckley et al., 2010; Kirby et al., 2013; Welker et al., 2016). The majority of the faunal remains identified through this method were uncertain specimens of sheep/goat or bovid. A summary of the faunal remains included in this study can be found in Table 3.

TABLE 3 Summary mean statistics of faunal remains to 1σ by site

Site	Species	δ^{13}C ‰	δ^{15}N ‰
Lisbon	Cattle (15)	−21.0 ± 0.5	6.1 ± 0.8
	Sheep (9)	−20.4 ± 0.6	6.2 ± 0.6
	Goat (3)	−19.9 ± 0.3	4.4 ± 0.5
	Pig (4)	−20.0 ± 0.6	7.8 ± 2.1
	Chicken (2)	−19.3 ± 0.9	7.2 ± 0.78
	Sheep/goat (1)	−20.5	5.3
	Dog (1)	−17.1	15.0[a]
Silves	Cattle (7)	−20.8 ± 0.8	6.8 ± 1.9
	Sheep (4)	−21.2 ± 0.4	6.7 ± 0.3
	Goat (3)	−20.4 ± 0.3	4.9 ± 1.0
	Pig (1)	−19.7	3.6
	Dog (2)	−20.6 ± 0.1	5.4 ± 2.0
Various sites	Marine fish (7)	−11.8 ± 0.5	11.3 ± 1.5

Note: Parentheses indicate number of individuals sampled.
[a]Statistical outlier.

2.4 | Collagen extraction and stable isotope analysis

Collagen was extracted following a modified Longin (1971) method including an ultrafiltration step (Brown et al., 1988). Bone was demineralised in

0.6 M HCl, and gelatinised in HCl at pH 3 at 80°C. The gelatinised fraction was ultrafiltered using Amicon 30 kDa filters, then frozen (~−20°C) and lyophilized. The collagen samples were analyzed in duplicate using isotope ratio mass spectrometry (IRMS) with a Sercon 20–22 at the BioArCh facilities, University of York. Isotopic values are reported following standard practice as the ratio of the heavier isotope to the lighter one (δ values in parts per mille, ‰) relative to internationally defined standards for carbon $^{13}C/^{12}C$ (VPDB, Vienna Pee Dee Belemnite) and nitrogen $^{15}N/^{14}N$ (AIR) following the equation [$\delta = (R_{sample} - R_{standard})/R_{standard} \times 1000$]. The analytical error for $\delta^{13}C$ and $\delta^{15}N$ was ±0.2‰ as determined by analysis of internal laboratory standards coupled with every run. The accuracy of measurements was monitored using international and in-house standards with well-known isotopic composition (in-house fish gelatine: $\delta^{13}C$ − 15.5 ± 0.1 ‰, $\delta^{15}N$ 14.3 ± 0.2 ‰; cane sugar IA-R006: $\delta^{13}C$ − 11.8 ± 0.1‰; caffeine IAEA 600: $\delta^{13}C$ − 27.8 ± 0.1‰, $\delta^{15}N$ 0.8 ± 0.1‰; ammonium sulfate IAEA N2: $\delta^{15}N$ 20.4 ± 0.2‰). Precision was <0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$ values. Collagen from all individuals in this study had acceptable C:N ratios, as well as C% and N%. Mann–Whitney U nonparametric tests were used for pairwise comparisons. The Pearson coefficient was used to test for correlation between nitrogen and carbon values. All statistics were performed in SPSS for Windows and $p \le 0.05$ was considered statistically significant.

2.5 | Bayesian stable isotope mixing modeling

The contribution of multiple food sources to diet can cause significant uncertainties when estimating food macronutrient composition (protein, carbohydrate and lipids) of past food intake. Bayesian Stable Isotope Mixings Models (BSIMMs) allow us to describe past diets through probability distributions of food sources, while taking into account several uncertainties (Fernandes et al., 2015; Phillips et al., 2014). As with any other statistical model FRUITS has its limitations. Firstly, it requires an isotopic baseline including the values of the most common food sources for that specific period and geographical area. Secondly, it needs enough dietary proxies ($\delta^{13}C$ and $\delta^{15}N$ in this case) that can target the food groups under study. Finally, it requires a quantification of diet-to-tissue isotopic offsets and dietary routing. Nonetheless, the model can handle uncertainties associated with all these parameters and provide useful probabilistic dietary models that estimate the relative contribution of different food sources to individual diets (Cheung & Szpak, 2020; Fernandes et al., 2015).

We used FRUITS 3.1 (Fernandes et al., 2014) and utilized a concentration-dependent and routed model, assuming that nitrogen isotopes are 100% sourced from proteins, while carbon isotopes can be sourced from carbohydrate and lipids depending on the diet (Jim et al., 2006). We opted for a two-food source model where the relative contribution of terrestrial and marine protein to diet was considered (Cubas et al., 2018). This methodological approach was considered the most suitable to the research question as well as the most conservative, as models with multiple source foods and only two proxies ($\delta^{13}C$ and $\delta^{15}N$) are often inconclusive and present larger uncertainties.

Additional details can be found in Data S1 Methodology, however, in brief, dietary proteins were considered to provide 74 ± 4% of bulk collagen carbon, while lipids and carbohydrates (i.e., energy) contributed the remainder (26%) (Fernandes et al., 2012). The model assumptions and parameters were following (Fernandes, 2016) and the isotopic composition of macronutrients in the faunal baseline was calculated from the average bulk collagen $\delta^{13}C$ and $\delta^{15}N$ values of terrestrial mammals and marine fish analyzed in this study at each site. Box and whisker plots were generated to summarize FRUITS dietary estimates. The horizontal lines correspond to the median and the hinges to the 25th (Q1) and 75th (Q3) percentile. Whiskers extends from the box to the smallest (≥−1.5) and largest observation (≤+1.5) within the interquartile range; outliers were excluded.

TABLE 4 Summary mean statistics to 1σ by site

Site	Period	Faith	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	Mann–Whitney test $p < 0.05$ $\delta^{13}C$ ‰	$\delta^{15}N$ ‰
Lisbon	EM[a] (18)	M	−18.8 ± 0.2	9.6 ± 0.7	$p < 0.000$ U = 830	$p < 0.000$ U = 845
	LM (46)	C	−17.9 ± 0.9	11.0 ± 1.2		
	LM[b] (22)	M	−18.2 ± 1.0[b]	10.8 ± 1.1[b]		
Beja	EM (41)	M	−19.1 ± 0.3	10.2 ± 0.7	$p < 0.000$ U = 497	$p < 0.000$ U = 504
	LM (14)	C	−18.5 ± 0.5	11.6 ± 0.9		
Silves	EM (26)	M	−18.6 ± 0.4	11.1 ± 1.1	$p < 0.000$ U = 838	$p = 0.257$ U = 577
	LM[c] (40)	C	−18.0 ± 0.6[c]	11.4 ± 0.9[c]		

Note: Parentheses indicate number of individuals sampled. The Mann–Whitney U tests were performed between EM and LM populations at each site combining LM Christians and Muslims in Lisbon.

Abbreviations: C, Christian; EM, early medieval; LM, late medieval; M, Muslim.

[a]Data from this study and 15 individuals from (13).

[b]Without outlier QDL104, with outlier, $\delta^{13}C = -17.8 \pm 2.3$‰, $\delta^{15}N = 10.7 \pm 1.1$‰.

[c]Without outliers RMB11B and LSE10, with outlier $\delta^{13}C = -17.8 \pm 1.1$‰, $\delta^{15}N = 11.3 \pm 1.0$‰.

3 | RESULTS

3.1 | Radiocarbon dating

The burial site at Beja included both Muslim and Christian individuals with several intercutting graves, which were originally interpreted by the archeologists as contemporaneous. However, due to a lack of grave goods and clear stratigraphy, we directly radiocarbon dated five individuals that were critical for our argument of a chronological diet change. Radiocarbon dating was performed on three Christian and two Muslim individuals buried in intercutting graves at Beja. Results (Table 2) indicate that the two Muslims date to the early medieval period (i.e., pre 1238 CE) while the Christians date to the post-conquest period (i.e., post 1238 CE). .

3.2 | Isotope analysis

Well preserved collagen was extracted from all sites in Lisbon, Beja and Silves, with collagen yields of >1% and C:N ratios between 2.9–3.6 (DeNiro, 1985) and atomic parameters within standards (C:N ratios, C% and N%) (Ambrose, 1990). The raw data for bulk collagen stable isotope analysis with indication of faith, chronology and sex for each individual is given in Data S1 (Table S5).

Isotopic analysis of a large number of animal remains ($n = 57$) provides both a baseline for the human diet but also information on husbandry practices. The summary data for animals from Lisbon and Silves are provided in Table 3. The $\delta^{13}C$ values for all domestic species range from −21.8‰ to −17.1‰ (4.7‰) and possess $\delta^{15}N$ values between 3.4‰ and 11.4‰ (8‰), not including one juvenile dog from Lisbon (LS2 7P) that is a significant statistical (>2σ from the population mean) outlier with an unusually high $\delta^{15}N$ value of 15‰. The analyzed species were predominantly domestic herbivores and their $\delta^{13}C$ values indicate a diet rich in C_3 plants with little to no input of C_4 resources. However, their $\delta^{15}N$ values have a high variability, for example, cattle $\delta^{15}N$ values range between 3.9‰ and 10.7‰. Herbivores (cattle, sheep and goat) and omnivores such as pig have very similar values; only one chicken from Lisbon possesses higher $\delta^{15}N$ values similar to the human population. Fish $\delta^{13}C$ and $\delta^{15}N$ values were both statistically different from terrestrial animals ($p < 0.000$) and ranged from −12.5‰ to −10.6‰ and 9.8‰ to 14.4‰, respectively. Fish $\delta^{13}C$ and $\delta^{15}N$ values were comparable with similar taxa from the Atlantic Iberian Peninsula of similar chronology (López-Costas & Müldner, 2018).

Data was produced from a total of 192 humans, to which we added an additional 15 individuals previously published from early medieval Lisbon (Toso et al., 2019) (Table 4). The $\delta^{13}C$ values of human individuals from early medieval (EM) Lisbon ranged from −18.5‰ to −19.4‰ while late medieval (LM) individuals ranged from −19.9‰ to −15.3‰ falling between and beyond the range of terrestrial animals at the same sites (Figure 2). At Beja $\delta^{13}C$ values span from −18.6‰ to −19.9‰ (EM) and from −17.7‰ to −19.8‰ (LM), while in Silves $\delta^{13}C$ values range between −17.7‰ and − 19.2‰ (EM) and − 12.5‰ to −18.9‰ (LM). The $\delta^{15}N$ values follow a similar pattern in Lisbon ranging from 8.5‰ to 11.2‰ (EM) and from 6.1‰ to 13.1‰ (LM) indicating a wider variety of protein sources for the later period. The pattern is different in Beja and Silves where $\delta^{15}N$ values are very similar for the early and late medieval period, ranging from 8.8‰ to 12.9‰ (Beja EM) and from 9.0‰ to 13.0‰ (Beja LM) and from 9.4‰ to 13.7‰ (Silves EM) and from 9.4‰ to 13.5‰ (Silves LM). Statistical outliers were identified, comprising three human individuals in Silves and Lisbon with significantly higher $\delta^{13}C$ values (RMB11B, LSE10, QDL104 $\delta^{13}C$ -12.5‰, −15.5‰, −8.2‰ respectively) but relatively low $\delta^{15}N$ values indicative of C_4 plant consumption. While these individuals were included in the scatter plots, they were not considered in any statistical analysis or BSIMM estimations. The full list of analyzed individuals with relative isotopic values can be found in Data S1.

At all sites, the $\delta^{13}C$ values of early medieval individuals are lower than those of the late medieval population at the same location, and this chronological trend is statistically significant (Table 4, Figure 3). A similar pattern is also observed in the $\delta^{15}N$ values, although it is less obvious and there is virtually no difference between the $\delta^{15}N$ values for the two faith groups in Silves. A correlation between $\delta^{13}C$ and $\delta^{15}N$ values is evident in the later medieval populations at all sites. Any correlation present between $\delta^{13}C$ and $\delta^{15}N$ values in the earlier periods is weak and insignificant by comparison (Data S1, Table S1). In the case of Silves, the early medieval population shows statistically significant correlation ($p = 0.032$), however, the later medieval group demonstrates a stronger correlation ($p < 0.000$).

For each time period (early medieval, late medieval) and location (Lisbon, Beja, and Silves) the average contribution of marine and terrestrial resources to protein in the human diet was estimated using BSIMMs. A simplified model including two source foods that is, marine and terrestrial resources was used. BSIMM analysis produced by FRUITS are intended here as a probabilistic estimation to understand the proportional relationships between food sources and not as an absolute quantification. No BSIMM can reliably differentiate among food groups with similar isotopic values and therefore we opted for a simplified two-source model (marine vs terrestrial protein). The lack of baseline values for the most commonly consumed crops (including C_4) and freshwater fish did not allow for a model with additional food sources. Although BSIMMs have clear limitations, they are a powerful tool to estimate the relative importance of food groups to past lifeways (Cheung & Szpak, 2020) and help visualize the difference in protein intake between the early and late medieval period in this study. The generated individual estimates for the two models (calories and protein) for all food sources deviated less than 5% at all sites, indicating that the model outputs were robust following the given parameters.

The model provides estimations on the caloric and protein contribution of each food source (marine resources and terrestrial resources) to diet. Tables S3 and S4 show that terrestrial resources (including terrestrial animals, its derivates and plants) contributed the majority of the caloric and protein intake across periods. This is not surprising, however while the model's predictions confirm the

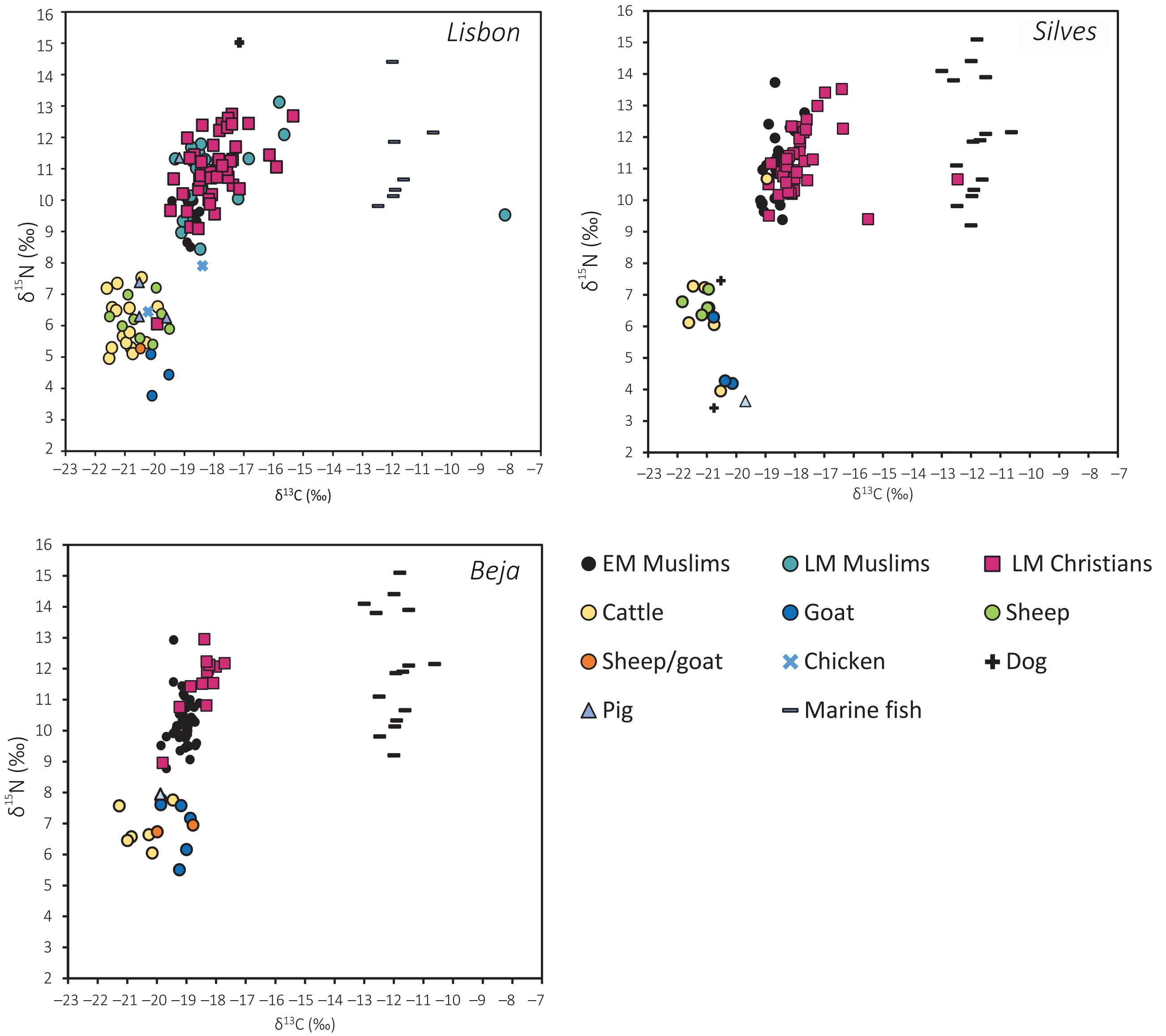

FIGURE 2 Bulk collagen δ^{13}C and δ^{15}N values of faunal and human individuals from Lisbon, Beja and Silves. EM Lisbon (n = 18); LM Lisbon (n = 68); EM Beja (n = 41); LM Beja (n = 14); EM Silves (n = 26); LM Silves (n = 40)

importance of crops and domestic animals to the diet, it also shows an increasing reliance on marine resources from the early to the late medieval period. The output from FRUITS indicates that the dietary (calories and protein) contribution of marine resources show a statistically significant change at all three sites from the early to the late medieval period (Data S1, Table S3 and Table S4). The protein estimates generated by the BSIMMs reflect this trend of increasing importance of marine resources as a protein source in the late medieval period (Figure 4). The model assigns a range of 2% to 4% protein gained from marine resources in early medieval Lisbon compared to 13% to 25% of protein in the late medieval period. Similarly, early medieval Beja shows ranges of marine protein between 2% to 5% compared to 2% to 10% for the early and late medieval periods, respectively. Silves also shows an increase in the amount of protein obtained from marine resources, going from 4% to 14% in the early medieval period to 4% to 39% in the late medieval. All estimations are significantly different between the early and late medieval period at all sites (Data S1, Table S4).

No difference was found between female and male individuals at any of the new sites presented in this study and detailed results and statistical tests for each group and at each site can be found in Data S1. Social status also could not be inferred; however, two examples are worth mentioning. The only Muslim female individual that had grave goods (QDL104) also showed a remarkably different diet with higher intake of C_4 plants (−8.2 ‰ δ^{13}C; 9.5 ‰ δ^{15}N) suggesting a potentially different geographical origin. One Christian female individual (BEJ4016) from Beja was buried with three bronze rings, however her diet was in keeping with the other Christian individuals. The Late Medieval Muslim individuals excavated in Lisbon at the site Largo das Olarias were effectively a religious minority living under Christian rule

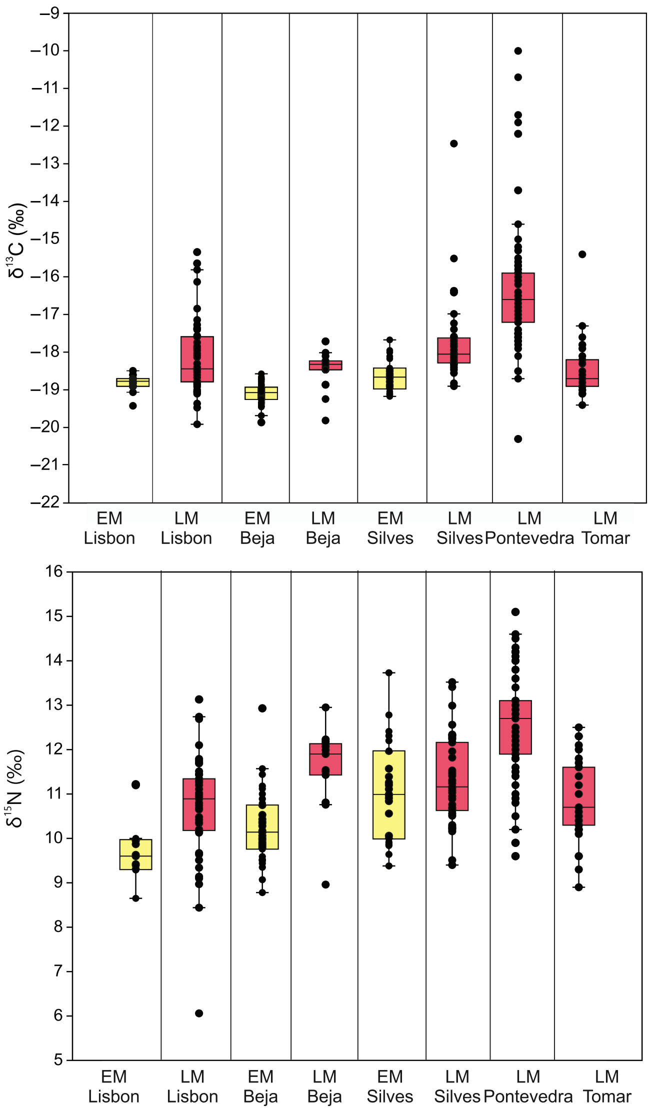

FIGURE 3 Bulk collagen $\delta^{13}C$ and $\delta^{15}N$ values of human individuals from all sites of Lisbon, Beja and Silves, compared to sites in Pontevedra and Tomar. EM = early medieval, LM = late medieval. EM Lisbon (n = 18); LM Lisbon (n = 68); EM Beja (n = 41); LM Beja (n = 14); EM Silves (n = 26); LM Silves (n = 40); LM Pontevedra (López-Costas & Müldner, 2018) (n = 63); LM Tomar (Curto et al., 2018) (n = 33)

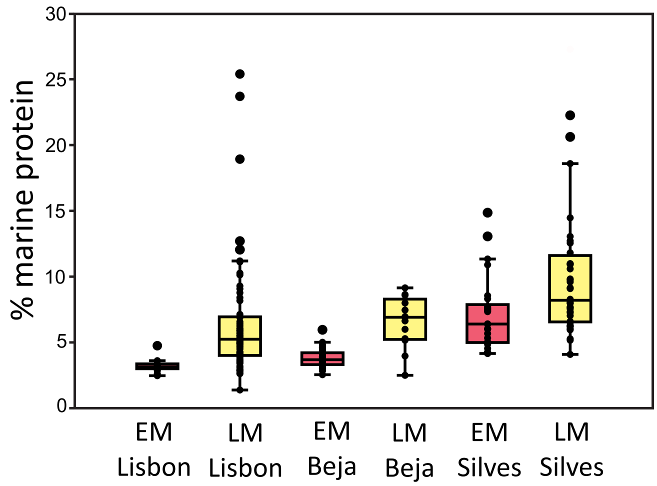

FIGURE 4 Percentage of marine protein in the diet of early (EM) and late (LM) medieval populations at all sites. Extreme outliers (QDL104, RMB11B, and LSE10) were not included. EM Lisbon (n = 18); LM Lisbon (n = 67); EM Beja (n = 41); LM Beja (n = 14); EM Silves (n = 26); LM Silves (n = 38)

and would have been subject to a stricter legislation in terms of living location and conditions which included access to specific occupations, food and specifically meat provisioning (Oliveira & Viana, 1993), however they show the same diet as the Cristian individuals from the same burial site and chronology.

Altogether, these results indicate a significant change in diet for all populations after the Christian conquest. This chronological trend follows faith identity in Beja and Silves where the early and late medieval populations are characterized either by Muslim or Christian individuals respectively. Both Muslims and Christians are, however, represented in the late medieval period in Lisbon and here both faiths possess enrichment in both $\delta^{13}C$ and $\delta^{15}N$ indicative of marine food consumption.

4 | DISCUSSION

Along the course of the Middle Ages (7–15th centuries) a number of extraordinary political, social, economic and religious changes swept the entire Iberian Peninsula, creating a unique mosaic of political systems, ethnicities, languages, faiths and economies. Historically, although the impact of the Christian conquest on society has received much attention, the implication of this socio-political transition for foodways and economy is poorly documented, and foodways of the preceding Islamic period in particular are relatively unknown in Portugal. The extensive isotopic dataset produced in this paper, comprising both Christian and Muslim populations before and after the Christian conquest, is the first isotopic study to address these gaps on a large chronological and geographical scale.

When considering the animal data for all sites, given the wide range in nitrogen values for herbivores (cow, sheep, and goat) and omnivores (chicken, swine), it is difficult to identify any preference in animal protein consumption by humans. In keeping with zooarchaeological evidence (Davis, 2008), it is likely that herbivores played a significant part in the diet of these populations, with omnivores such as chickens supplementing the diet of some, particularly those with higher nitrogen values among the early medieval Islamic populations. Zooarchaeological and historical evidence indicate changes in the animal economy between the early and late medieval period across the Iberian Peninsula. For example, sheep increased in size in southern Portugal from Roman to Islamic period and experienced another increase during the later Christian period (Davis, 2008). Late Christian sites possess fewer sheep remains compared to Islamic sites, with the opposite trend seen in cattle (Grau-Sologestoa, 2017). The late medieval period saw a reorganization of the agricultural landscape with more intensive crop cultivation and large-scale animal husbandry (Marques, 1962). The effects of this change have been observed in faunal isotopic values in Valencia (Alexander et al., 2019). However, the transition in Southern Portugal is less clear since the prolonged use of Islamic pottery at many sites, hinder the identification of a precise chronology (Valente, 2019). In addition, because of the lack of direct dating of animal remains, changes in husbandry practices between the early and the late medieval period cannot be explored with this dataset.

The isotopic data indicate that these urban human populations were subsisting on C_3 plants, and terrestrial animal resources as their main dietary source especially in the early medieval period. There is some evidence for direct C_4 plant consumption by humans, although we exclude C_4 fed protein as animal diets are exclusively C_3. Outliers with high $\delta^{13}C$ values in late medieval Silves and Lisbon (RMB11B, LSE10, QDL104), will have had a significant component of C_4 plant in their diet and it is unlikely that these individuals were locals. Proximate areas that relied more significantly on C_4 plants include northern Portugal and Galicia (López-Costas & Müldner, 2018). Furthermore, the isotopic data show the appearance of marine resources as a significant source of protein during the late medieval period while they seem to have a negligible contribution to diet under Muslim rule.

Historical sources suggest that men and women had a different role in Islamic and Christian medieval societies that extended to both the public and private sphere of life (Marín, 2000). However, the isotopic results indicate that statistically significant differences in diet between males and females exist only at the high-status Muslim burial ground of São Jorge Castle in Lisbon (Toso et al., 2019). The lack of dietary differentiation between sexes at all the other sites suggests a similar access to food. Since no specific indication of high status is known for these burials, these sites are likely to represent the general urban medieval population of a middle-low status. Smaller households and spaces of multifunctional purpose might have hindered the physical separation of space that is typical for higher status households and fostered a similarity in dietary practices and food access (Diez Jorge, 2002). Sex differences in diet are a rare occurrence among published datasets of Muslim populations from Spain (Fuller et al., 2010; Salazar-García et al., 2016; Alexander et al., 2015). Significant differences between sexes have been reported for a number of Christian medieval sites in the UK such as Newark Bay, Orkney (Richards et al., 2006), York (Müldner & Richards, 2007), Trino Vercellese, Italy (Reitsema & Vercellotti, 2012), Giecz, Poland (Reitsema et al., 2010), Solt-Tételhegy, Hungary (Gugora et al., 2018) and the Czech Republic (Kaupová et al., 2018); however no similar trend was found in medieval Christian populations in the Iberian Peninsula so far (Jordana et al., 2019; Lubritto et al., 2017; MacKinnon et al., 2019). Although historical sources may allude to the different role of males and females in the medieval society and their different participation in food processing and consumption, it may be that the difference is too subtle to be detected using bulk collagen isotopic analysis (Müldner & Richards, 2006). Despite the obvious limitations of the technique, further research in microhistory might prove particularly useful to explore themes of identity, gender and family organization in past societies.

Most significantly, the isotopic data, supported by BSIMMs indicates that marine fish were not a major part of the diet for any of the early medieval populations analyzed here, despite the coastal proximity of Lisbon and Silves. This is similar to what has been observed in the Balearic Islands (Fuller et al., 2010; Pickard et al., 2017), where, despite the easy access to marine resources, the diet of the Muslim population tended to be mainly terrestrial; and in zooarchaeological assemblages in Southern Portugal where little in the way of fish remains were recovered regardless of their coastal proximity (Valente & Marques, 2017; Valente & Martins, 2015). Cultural preference played a key role in food choice and cookery books and medical treatises from the time (12th-14th) pay little attention to fish and its preparations (García-Sánchez, 1986). Early medieval diet, however, is characterized by high variability which is apparent both in historical (i.e., people in Cairo did eat fish) (Lewicka, 2011) and archeological sources (García-García, 2017; Lubritto et al., 2017). Our dataset shows a difference in the contribution of marine resources to the diet between the three sites, with possible freshwater fish consumption in Silves during the early medieval period. A new importance of marine resources in the later medieval period is indicated by our results showing that fish, and more generally marine resources, made a more significant dietary contribution in terms of both caloric and protein intake after the Christian conquest, regardless of religious affiliation. However, the possible consumption of freshwater fish and minor quantities of C_4 plants at Silves may attenuate this signal.

This is the first time that an increase in fish consumption has been identified in the transition between early to late medieval societies in the Iberian Peninsula, which brings Portugal into line with the NW Europe 'fish horizon', if at a slightly later chronology (>11th century CE, Barrett et al., 2011). On a regional scale, isotopic data for late medieval and early modern populations (13–17th centuries) from Pontevedra on the coast of Galicia indicate a similar level of marine consumption (Figure 3), supported by historical sources concerning local fish commerce (López-Costas & Müldner, 2018). A late medieval-early modern Portuguese population from Tomar (Curto et al., 2018) does not, however, show a significant intake of marine resources, with $\delta^{13}C$ and $\delta^{15}N$ values that are in between the early and late medieval populations here (Figure 3). This suggests a mixed diet in which animal protein and potentially freshwater fish were widely consumed with marine resources only complementing the diet of a few individuals (Curto et al., 2018). However, the data from Tomar represents a wide chronology of seven centuries, which may not be a wholly representative snapshot of the diet over this time period. By the early modern period, a decline of the fishing industry was documented for Galicia (López-Costas & Müldner, 2018). After the 16th century in Portugal, the Crown became more interested in the expansion of trade routes in the South Atlantic and Indian Oceans as opposed to fishing, as supported by a documented increase in 'sailors' as opposed to 'fishermen' (Amorim, 2009). The fishing sector saw further expansion in the 18th century, however during this period less fishermen were active off the Algarvian coast and instead there was an increase (48% to 250%) in fishermen working along the coasts of Minho and Douro, Coimbra and Aveiro (Amorim, 2009). After 1830, the revival of

Portuguese fishing activity off Newfoundland took place due to the adoption of new fishing methods and a new way of salting sardines (Amorim, 2009).

4.1 | Fish consumption: Disentangling faith and chronology

Christian fasting is often directly linked to the increased consumption of marine protein in late medieval Christian populations (Woolgar, 2003). In this case however, both Muslims and Christians from late medieval Lisbon show a major reliance on marine resources, which is in stark contrast to the preceding Islamic period. This suggests that fish was widely accessible in the markets of the late medieval period, not only in the northern cities, as documented by historical sources, but also in the south of Portugal where fish was widely consumed by the population, including low status religious minorities living under Christian rule (Barros, 2015). The chronological trend indicates that faith was not the only factor that shaped the diet of urban dwellers in medieval Portugal. The political shift brought about by the conquest will have played an equally important role in defining food access and resource availability, especially for urban centers.

This calls us to move beyond interpretations driven by differences in cultural preferences and faith identities and to consider wider political and economic developments occurred after the Christian conquest. Historical sources indicate that in the 13th century English rulers were among the first to grant safe conduct to Portuguese vessels to fish in their waters. Strong relationships continued through the medieval period (Childs, 1992) and in 1226, Henry III (1216–72) allowed 106 merchants from Portugal to trade freely in England for one year (Miranda, 2013). In 1353, King Edward III (1312–1377) signed a commercial treaty with Portuguese ambassadors to allow Portuguese fishermen to carry on their industry off the coasts of England and Brittany (Childs, 1992). The reasons behind this rapid expansion of the Portuguese fishing industry are multifaceted. Similar to what has been observed in England, where fish catchment areas were dramatically extended offshore to meet demand (Barrett et al., 2011), an overexploitation of in-shore resources could have initiated this phenomenon in Portugal as well. There are historical records of a number of petitions to the King and local regulations in the 15th century to stop exporting fish from Porto, Vila do Conde and Lisbon for fear of fish shortages, and speculation on fish (especially sardines and cod) became a concern for those of higher and lower status alike (Amorim, 2009). What prompted this demand-driven intensification of local fishing is difficult to pinpoint. It is undoubtable that after the Christian conquest and conversion, Christian fasting will have been a factor in higher demand for fish supply, however it was notthe only reason behind this new interest in fish (McCleery, 2018). Fishermen were held responsible for sustaining such eating habits by royal and municipal laws, especially during Lent (Moreira, 1987). However, population growth and the shortage of other foodstuffs such as grain, will have also contributed. Historical records report a population explosion in the 16th century, coinciding with an economic growth of coastal towns thanks to rising levels of Atlantic trade. For example, the population of Lisbon went from 70,000 inhabitants in 1528, to 100,000 in 1550 and 165,000 in 1619 (Amorim, 2009). Fish was an affordable source of protein and the demand to feed growing urban centers will have increased the pressure on food resources. Some species remained expensive and accessible only to the few, both marine (croaker, red porgy, red bream, and hake) and freshwater (including lamprey and eel). However, less expensive fish (sardines, sole and allis shad) were in abundance and would be easily accessible by those of lower status (Martins, 2016), like the Muslim community living under Christian rule in Lisbon in this study. The cost and the availability of fish coupled with the easy access to salt along the whole Portuguese coastline coincided to expand fishing activities into the creation of a wider fishing industry (Antunes, 2008; Newstead, 2014).

5 | CONCLUSIONS

In this study, isotopic data supported by BSIMMs has provided unique insight into the contribution of different food sources to individual diet in combination with archeological and historical data. Results indicate that the late medieval population obtained more of their dietary intake from marine resources, equally across both sexes and faiths indicating that this resource was widely available in significant quantities to all strata of society, including religious minorities. The change from a predominantly terrestrial diet to one with a heavy marine component provides unprecedented archeological evidence for the prelude to the early-modern Portuguese marine economy and its global expansion.

ACKNOWLEDGMENTS

The authors wish to thank Sonia Ferro and Tiago Curado for assistance during the archeological work undertaken in Largo das Olarias. The authors are also grateful to Matthew Von Tersch for assistance in mass spectrometry and to Dr. David Orton and Dr. Laura Llorente-Rodriguez who identified the fish remains. Grant sponsor: AHRC PhD Network Studentship awarded (White Rose College of the Arts and Humanities at the University of York); Santander International Connection award 2014; Barakat Trust Award 2015; Archaeology of Portugal Fellowship 2016; BioArCh, Department of Archaeology, University of York.

CONFLICT OF INTEREST

This statement is to certify that the authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Alice Toso: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology. **Simona Schifano:** Data curation; formal analysis; investigation; writing-review & editing. **Charlotte Oxborough:** Data curation; formal analysis; investigation; writing-original draft; writing-review & editing. **Krista McGrath:** Data curation; formal analysis; investigation; methodology; writing-review &

editing. **Luke Spindler:** Formal analysis; investigation; methodology; writing-review & editing. **Anabela Castro:** Investigation; resources; writing-review & editing. **Lucy Evangelista:** Investigation; resources; - writing-review & editing. **Vanessa Filipe:** Investigation; resources; writing-review & editing. **Maria João Gonçalves:** Investigation; resources; writing-review & editing. **Antonio Marques:** Investigation; resources; writing-review & editing. **Inês Mendes da Silva:** Investigation; resources; writing-review & editing. **Raquel Santos:** Investigation; resources; writing-review & editing. **Maria João Valente:** Investigation; resources; writing-original draft; writing-review & editing. **Iona McCleery:** Conceptualization; investigation; project administration; supervision; writing-original draft; writing-review & editing. **Michelle Alexander:** Conceptualization; funding acquisition; investigation; methodology; project administration; supervision; writing-original draft; writing-review & editing.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article and will be stored in the IsoArcH repository (https://www.re3data.org/repository/r3d100013383).

ORCID

Alice Toso https://orcid.org/0000-0003-3469-1412
Michelle Alexander https://orcid.org/0000-0001-8000-3639

REFERENCES

Alexander, M. M., Gerrard, C. M., Gutiérrez, A., & Millard, A. R. (2015). Diet, society, and economy in late medieval Spain: Stable isotope evidence from Muslims and Christians from Gandía, Valencia. *American Journal of Physical Anthropology*, *156*(2), 263–273.

Alexander, M. M., Gutiérrez, A., Millard, A. R., Richards, M. P., & Gerrard, C. M. (2019). Economic and socio-cultural consequences of changing political rule on human and faunal diets in medieval Valencia (c. fifth–fifteenth century AD) as evidenced by stable isotopes. *Archaeological and Anthropological Sciences*, *11*, 3875–3893.

Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, *17*(4), 431–451.

Amorim, I. (2009). Chapter eight. The evolution of Portuguese fisheries in the medieval And early modern period a fiscal approach. In L. Sicking & D. Abreu-Ferreira (Eds.), *Beyond the catch. Fisheries of the North Atlantic, the North Sea and the Baltic, 900-1850* (pp. 245–279). Brill.

Antunes, C. A. P. (2008). Aveiro and Setúbal, 1580-1680: Competition and integration of the Portuguese salt ports in the northern European markets. In I. Amorim (Ed.), *Articulação do Sal Português aos circuitos mundiais. Antigos e novos consumos. The articulation of Portuguese salt with worldwide routes. Past and new consumption trends* (pp. 161–182). Instituto de História Moderna/Universidade do Porto.

Arneborg, J., Heinemeier, J., Lynnerup, N., Nielsen, H. L., Rud, N., & Sveinbjörnsdóttir, Á. E. (1999). Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and 14C dating of their bones. *Radiocarbon*, *41*(2), 157–168.

Azevedo, M. R. (1982). O bacalhau na economia Portuguesa. *Revista de Marinha*, *110*, 9–15.

Barrett, J. H., Orton, D., Johnstone, C., Harland, J., Van Neer, W., Ervynck, A., … Richards, M. (2011). Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. *Journal of Archaeological Science*, *38*(7), 1516–1524.

Barros, M. F. (2015). Conviver na Cidade: muçulmanos na Mouraria de Lisboa nos séculos XV e XVI. In F. Sabaté (Ed.), *Formes de convivência a la Baixa Edat Mitjana* (pp. 127–142). Aurembiaix d'Urgell.

Branco, R., & Valente, M. J. (2015). Análise zooarqueológica de vertebrados e invertebrados do material proveniente da Ocupação Islâmica da casa das Bicas (Loulé). In N. M. Rosales (Ed.), *Actas do VII Encontro de Arqueologia do Sudoeste peninsular, Aroche - Serpa* (pp. 935–949). Ayuntamento de Aroche/Câmara Municipal de Serpa.

Bronk Ramsey, C. (2008). Radiocarbon dating: Revolutions in understanding. *Archaeometry*, *50*(2), 249–275.

Brown, T. A., Nelson, D. E., Vogel, J. S., & Southon, J. R. (1988). Improved collagen extraction by modified Longin method. *Radiocarbon*, *30*(2), 171–177.

Buckley, M., Whitcher Kansa, S., Howard, S., Campbell, S., Thomas-Oates, J., & Collins, M. (2010). Distinguishing between archaeological sheep and goat bones using a single collagen peptide. *Journal of Archaeological Science*, *37*(1), 13–20.

Casimiro, T. M., Chanoca, C., & Vieira, A. I. (2008). Silves polis 2004-2006: Duas necrópoles medievais cristãs. *Xelb*, *8*, 243–253.

Catarino, M. M. (1998). *Na margem direita do Baixo Tejo: Paisagem rural e recursos alimentares (secs. XIV e XV) (Mestrado)*. Universidade de.

Cheung, C., & Szpak, P. (2020). Interpreting past human diets using stable isotope mixing models. *Journal of Archaeological Method and Theory*, *2020*. https://doi.org/10.1007/s10816-020-09492-5

Childs, W. R. (1992). Anglo-Portuguese trade in the fifteenth century. *Transactions of the Royal Historical Society*, *2*, 195–219.

Christys, A. (2009). Communities of the dead in Umayyad Cordoba. *Al-Masaq*, *21*(3), 289–299.

Coelho, M. H. d. C. (1995). A Pesca fluvial na economia e sociedade medieval Portuguesa. *Cadernos Históricos VI*, *4*, 81–102.

Cole, S. (1990). Cod, god, country and family:The Portuguese Newfoundland cod fishery. *Maritime Anthropological Studies*, *3*(1), 1–29.

Collins, R. (1994). *Early medieval Spain: Unity in diversity, 400–1000*. Macmillan.

Constable, O. R. (1996). *Trade and traders in Muslim Spain: The commercial realignment of the Iberian Peninsula, 900–1500*. Cambridge University Press.

Cubas, M., Peyroteo-Stjerna, R., Fontanals-Coll, M., Llorente-Rodríguez, L., Lucquin, A., Craig, O. E., & Colonese, A. C. (2018). Long-term dietary change in Atlantic and Mediterranean Iberia with the introduction of agriculture: A stable isotope perspective. *Archaeological and Anthropological Sciences.*, *11*, 3825–3836. https://doi.org/10.1007/s12520-018-0752-1

Curto, A., Maurer, A.-F., Barrocas-Dias, C., Mahoney, P., Fernandes, T., & Fahy, G. E. (2018). Did military orders influence the general population diet? Stable isotope analysis from medieval Tomar, Portugal. *Archaeological and Anthropological Sciences*, *11*, 3797–3809.

Davis, S. J. M. (2008). Zooarchaeological evidence for Moslem and Christian improvements of sheep and cattle in Portugal. *Journal of Archaeological Science*, *35*(4), 991–1010.

DeNiro, M. J. (1985). Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, *317*(6040), 806–809.

Díez Jorge, M. E. (2002). El espacio doméstico: lo femenino y lo masculino en la ciudad palatina de la Alhambra. *Cuadernos de la Alhambra*, *38*, 155–181.

Estaca-Gómez, V., Malalana-Ureña, A., Yravedra, J., Matás, G. J. L., & de Pablos, J. M. (2018). Economic implications of livestock management strategies in the center of the Iberian Peninsula, Tagus Basin, and Mancha Alta region between the VIII and XI centuries AD. *Archaeological and Anthropological Sciences*, *11*, 1289–1305.

Fernandes, R. (2016). A simple(R) model to predict the source of dietary carbon in individual consumers. *Archaeometry*, *58*(3), 500–512.

Fernandes, R., Grootes, P., Nadeau, M.-J., & Nehlich, O. (2015). Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): The case study of Ostorf (Germany). *American Journal of Physical Anthropology*, *158*(2), 325–340.

Fernandes, R., Millard, A. R., Brabec, M., Nadeau, M.-J., & Grootes, P. (2014). Food reconstruction using isotopic transferred signals (FRUITS): A Bayesian model for diet reconstruction. *PLoS One*, *9*(2), e87436.

Fernandes, R., Nadeau, M.-J., & Grootes, P. M. (2012). Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. *Archaeological and Anthropological Sciences*, *4*(4), 291–301.

Fierro Bello, M. I. (2000). El espacio de los muertos: Fetuas andalusíes sobre tumbas y cementerios. In M. I. Fierro Bello, J. P. van Staëvel, & P. Cressier (Eds.), *L'urbanisme dans l'occident musulman au moyen âge: Aspects juridiques* (pp. 153–190). Casa de Velázquez/Consejo Superior de Investigaciones Científicas, CSIC.

Filipe, V., Vieria, V., Ferro, S., Pereira, T., & Neves, D. (2020). *Relatório final dos trabalhos arqueológicos desenvolvidos no Poço do Borratém no âmbito do Projeto de instalação de ecopontos subterrâneos na cidade de Lisboa. Relatório Policopiado Direção Geral do Património cultural* (Vol. 80, p. 86). Cota.

Filipe, V., Toso, A., & Inocêncio, J. (2018). *Perspectivas arqueobiológicas sobre a necrópole islâmica de Alfama. I Encontro de Arqueologia de Lisboa: Uma Cidade Em Escavação*. CAL/DPC/DMC/CML.

Fuller, B. T., Márquez-Grant, N., & Richards, M. P. (2010). Investigation of diachronic dietary patterns on the islands of Ibiza and Formentera, Spain: Evidence from carbon and nitrogen stable isotope ratio analysis. *American Journal of Physical Anthropology*, *143*(4), 512–522.

Gamito, T. J., Lensch, G., Marschall, K., Oliveira, L., & da Veiga, I. A. (1997). A Sé de Silves: A memória da Pedra. *Arqueologia Medieval*, *5*, 227–293.

García-García, M. (2017). Some remarks on the provision of animal products to urban centres in medieval Islamic Iberia: The cases of Madinat Ilbirah (Granada) and Cercadilla (Cordova). *Quaternary International: The Journal of the International Union for Quaternary Research*, *460*, 86–96.

García-Sánchez, E. (1983). La alimentacion en la Andalusia Islamica. Estudio Historico y Bromatologico I: Cereales y leguminosas. In J. Bosch Vila & W. Hoenerbach (Eds.), *Andalusia Islamica. Textos y Estudios* (pp. 140–177). Universidad de Granada.

García-Sánchez, E. (1986). La alimentación el la Andalucia islamica. Estudio Histórico y Bromatológico II: Carne, pescado, huevos, leche y productos lacteos. In J. Bosch Vila & W. Hoenerbach (Eds.), *Andalucia Islamica. Textos y Estudios* (pp. 237–278). Universidad de Granada.

García-Sánchez, E. (1992). Agriculture in Muslim Spain. In S. K. Jayyusi (Ed.), *The legacy of Muslim Spain* (pp. 987–999). E.J. Brill.

García-Sánchez, E. (1996). La alimentación popular Urbana en al-Andalus. *Arqueologia Medieval*, *4*, 219–235.

Gomes, M., Santos, R., & Vilhena de Carvalho, M. L. (2014). *Intervenção arqueológica na Escola Secundária Diogo Gouveia – Beja*. Neoepica Lda.

Gonçalves, I. (1984). *O temporal do Mosteiro de Alcobaça nos Séculos XIV e XV* (Vol. 1). Faculdade de Ciências Sociais e Humanas da Universidade Nova de Lisboa.

Grau-Sologestoa, I. (2017). Socio-economic status and religious identity in medieval Iberia: The zooarchaeological evidence. *Environmental Archaeology*, *22*(2), 189–199.

Gugora, A., Dupras, T. L., & Fóthi, E. (2018). Pre-dating paprika: Reconstructing childhood and adulthood diet at medieval (13th century CE) Solt-Tételhegy, Hungary from stable carbon and nitrogen isotope analyses. *Journal of Archaeological Science: Reports*, *18*, 151–160.

Insoll, T. (1999). *The archaeology of Islam*. Wiley.

Jim, S., Jones, V., Ambrose, S. H., & Evershed, R. P. (2006). Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. *The British Journal of Nutrition*, *95*(6), 1055–1062.

Jordana, X., Malgosa, A., Casté, B., & Tornero, C. (2019). Lost in transition: The dietary shifts from late antiquity to the early middle ages in the north eastern Iberian Peninsula. *Archaeological and Anthropological Sciences*, *11*, 1–13. https://doi.org/10.1007/s12520-019-00777-9

Kaupová, S., Velemínský, P., Herrscher, E., Sládek, V., Macháček, J., Poláček, L., & Brůžek, J. (2018). Diet in transitory society: Isotopic analysis of medieval population of Central Europe (ninth–eleventh century AD, Czech Republic). *Archaeological and Anthropological Sciences*, *10*(4), 923–942.

Kennedy, H. (1996). *Muslim Spain and Portugal: A political history of al-Andalus*. Longman.

Kirby, D. P., Buckley, M., Promise, E., Trauger, S. A., & Holdcraft, T. R. (2013). Identification of collagen-based materials in cultural heritage. *The Analyst*, *138*(17), 4849–4858.

Lewicka, P. (2011). *Food and foodways of medieval Cairenes: Aspects of life in an Islamic metropolis of the eastern Mediterranean*. Brill.

Longin, R. (1971). New method of collagen extraction for radiocarbon dating. *Nature*, *230*(5291), 241–242.

López-Costas, O., & Alexander, M. (2019). Paleodiet in the Iberian Peninsula: Exploring the connections between diet, culture, disease and environment using isotopic and osteoarchaeological evidence. *Archaeological and Anthropological Sciences*, *11*(8), 3653–3664.

López-Costas, O., & Müldner, G. (2018). Boom and bust at a medieval fishing port: Dietary preferences of fishers and artisan families from Pontevedra (Galicia, NW Spain) during the late medieval and early modern period. *Archaeological and Anthropological Sciences*, *11*, 3717–3731.

Lubritto, C., García-Collado, M. I., Ricci, P., Altieri, S., Sirignano, C., & Quirós Castillo, J. A. (2017). New dietary evidence on medieval rural communities of the Basque Country (Spain) and its surroundings from carbon and nitrogen stable isotope analyses: Social insights, diachronic changes and geographic comparison: Palaeodietary evidence on medieval Basque rural communities. *International Journal of Osteoarchaeology*, *27*(6), 984–1002.

MacKinnon, A. T., Passalacqua, N. V., & Bartelink, E. J. (2019). Exploring diet and status in the medieval and modern periods of Asturias, Spain, using stable isotopes from bone collagen. *Archaeological and Anthropological Sciences*, *11*, 3837–3855.

Marín, M. (2000). Mujeres en al-Andalus. In C. del Moral (Ed.), *Árabes, judías y cristianas* (Vol. 11, pp. 35–52). Consejo superior de investigaciones científicas.

Marques, A. H. d. O. (1962). *Introdução à história da agricultura em Portugal: A questão cerealífera durante a Idade Média*. Cosmos.

Marques, A. H. d. O. (1987). *Portugal na crise dos séculos XIV e XV*. Editorial Presença.

Marques, A. H. d. O. (1993). *Nova Historia de Portugal*. Editorial Presença.

Martins, L. (2016). *Contributos Para a historia da alimentação algarvia a partir das atas de vereação do concelho de Loulé (1384–1488)*. Direcção regional da Cultura do Algarve.

McCleery, I. (2018). Holy but not healthy? Fish-eating in the middle ages. *Medieval Yorkshire*, *2*(5), 49–63.

Miranda, F. (2013). Before the empire: Portugal and the Atlantic trade in the late middle ages. *Journal of Medieval Iberian Studies*, *5*(1), 69–85.

Monge Soares, A. M. (1993). The ^{14}C content of marine shells: Evidence for variability in coastal upwelling off Portugal during the Holocene. In IAEA (Ed.), *Isotope techniques in the study of past and current environmental changes in the hydrosphere and the atmosphere*. IAEA.

Monge Soares, A. M., Gutiérrez-Zugasti, I., González-Morales, M., Matos Martins, J. M., Cuenca-Solana, D., & Bailey, G. N. (2016). Marine radiocarbon reservoir effect in late Pleistocene and early Holocene coastal waters off northern Iberia. *Radiocarbon*, *58*(4), 869–883.

Monge Soares, A. M., & Martins, J. M. M. (2009). Radiocarbon dating of marine shell samples. The marine radiocarbon reservoir effect of coastal waters off Atlantic Iberia during late Neolithic and chalcolithic periods. *Journal of Archaeological Science*, *36*(12), 2875–2881.

Morales-Muñiz, A., Moreno, M., Roselló, E., Llorente, L., & Morales, D. C. (2011). 711 AD: El origen de una disyunción alimentaria?. *Arqueologia E Historia Entre Dos Mundos*, *15*, 303–322.

Moreira, C. D. (1987). *Populações marítimas em Portugal*. Instituto Superior de Ciencias Sociais e Politicas.

Müldner, G., & Richards, M. P. (2007). Diet and diversity at later medieval Fishergate: The isotopic evidence. *American Journal of Physical Anthropology*, *134*(2), 162–174.

Müldner, G., & Richards, M. P. (2006). Diet in medieval England: The evidence from stable isotopes. In C. M. Woolgar, D. Serjeantson, & T. Waldron (Eds.), *Food in medieval England: Diet and nutrition* (pp. 228–238). Oxford University Press.

Newstead, S. (2014). Cod, salt and wine: Tracing Portuguese pottery in the English North Atlantic world. *North Atlantic Archaeology*, *3*, 75–92.

Oliveira, L. F., & Viana, M. A. (1993). Mouraria de Lisboa no século XV. *Arqueologia medieval*, *2*, 191–210.

Pellat, C., Sourdel-Thomine, J., Elwell-Sutton, L. P., & Boratav, P. N. (2012). Ḥayawān. In P. Bearman, Th. Bianquis, C.E. Bosworth, E. van Donzel, W.P. Heinrichs (Eds.) *Encyclopaedia of Islam* (2nd ed.):Brill.

Petersen, A. (2013). The archaeology of death and burial in the Islamic world. In L. N. S. And (Ed.), *The Oxford handbook of the archaeology of death and burial*. Oxford University Press.

Pickard, C., Girdwood, L.-K., Kranioti, E., Márquez-Grant, N., Richards, M. P., & Fuller, B. T. (2017). Isotopic evidence for dietary diversity at the mediaeval Islamic necropolis of can Fonoll (10th to 13th centuries CE), Ibiza, Spain. *Journal of Archaeological Science: Reports*, *13*, 1–10.

Phillips, D. L., Inger, R., Bearhop, S., Jackson, A. L., Moore, J. W., Parnell, A. C., Semmens, B. X., & Ward, E. J. (2014). Best practices for use of stable isotope mixing models in food-web studies. *Canadian Journal of Zoology*, *92*(10), 823–835.

Reimer, P. J., Bard, E., Bayliss, A., Warren Beck, J., Blackwell, P. G., Ramsey, C. B., … van der Plicht, J. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*, *55*(4), 1869–1887.

Reitsema, L. J., Crews, D. E., & Polcyn, M. (2010). Preliminary evidence for medieval polish diet from carbon and nitrogen stable isotopes. *Journal of Archaeological Science*, *37*(7), 1413–1423.

Reitsema, L. J., & Vercellotti, G. (2012). Stable isotope evidence for sex- and status-based variations in diet and life history at medieval Trino Vercellese, Italy. *American Journal of Physical Anthropology*, *148*(4), 589–600.

Richards, M. P., Fuller, B. T., & Molleson, T. I. (2006). Stable isotope palaeodietary study of humans and fauna from the multi-period (iron age, Viking and late medieval) site of Newark Bay, Orkney. *Journal of Archaeological Science*, *33*, 122–131.

Ruiz-Taboada, A. (2015). Comments on Muslim, Jewish and Christian burial practices in medieval Toledo (Spain). *Journal of Islamic Archaeology*, *2*(1), 51–71.

Salazar-García, D. C., Romero, A., García-Borja, P., Subirà, M. E., & Richards, M. P. (2016). A combined dietary approach using isotope and dental buccal-microwear analysis of human remains from the Neolithic, Roman and medieval periods from the archaeological site of Tossal de les basses (Alicante, Spain). *Journal of Archaeological Science: Reports*, *6*, 610–619. https://doi.org/10.1016/j.jasrep.2016.03.002

Santos, C. L., Barbosa, C. S., & Ramos, S. (2008). Contributo da antropologia biológica Para a História de Silves: Resultados das intervenções arqueológicas durante o programa polis (2004-2006). *Xelb*, *8*, 417–430.

Santos, C., Fregel, R., Cabrera, V. M., Alvarez, L., Larruga, J. M., Ramos, A., … González, A. M. (2014). Mitochondrial DNA and Y-chromosome structure at the Mediterranean and Atlantic façades of the Iberian Peninsula. *American Journal of Human Biology: The Official Journal of the Human Biology Council*, *26*(2), 130–141.

Saragoça, P., Maurer, A.-F., Šoberl, L., Lopes, M. d. C., Alfenim, R., Leandro, I., Umbelinoef, C., Fernandeseg, T., Valentebh, M. J., Santosi, J. F., Janeiro, A. I., & Barrocas, C. D. (2016). Stable isotope and multi-analytical investigation of Monte da Cegonha: A late antiquity population in southern Portugal. *Journal of Archaeological Science: Reports*, *9*, 728–742.

Serra, M. (2012). Analise Arqueológica da necrópole islâmica de Beja. *Arqueologia Medieval*, *12*, 235–245.

Soares, A. M., & Dias, J. M. (2006). Coastal upwelling and radiocarbon—Evidence for temporal fluctuations in ocean reservoir effect off Portugal during the Holocene. *Radiocarbon*, *48*(1), 45–60.

Simões, J. M. (2012). *História económica, social e Urbana de Loulé*. Câmara Municipal de Loulé.

Strohalm, M., Hassman, M., Kosata, B., & Kodícek, M. (2008). mMass data miner: An open source alternative for mass spectrometric data analysis. *Rapid Communications in Mass Spectrometry: RCM*, *22*(6), 905–908.

Toso, A., Gaspar, S., Banha da Silva, R., Garcia, S. J., & Alexander, M. (2019). High status diet and health in medieval Lisbon: A combined isotopic and osteological analysis of the Islamic population from São Jorge Castle, Portugal. *Archaeological and Anthropological Sciences*, *11*, 3699–3716.

Valente, M. J. (2019). Between medieval worlds: Zooarchaeological problematics in the Islamic-Christian transitions in southwest Iberian contexts. In M. A. Valladares & M. J. Valente (Eds.), *Workshop Internacional Minorías y transiciones en la Edad media a través de la Zooarqueología (siglos X-XV) Granada, 28–29 novembrie 2019* (pp. 1–29). Facultad de Filosofia y Letra, Universidad de Granada.

Valente, M. J., & Marques, A. (2017). Alimentação mudéjar em Lisboa: Dados preliminares sobre a zooarqueologia do largo da Severa (Mouraria, Lisboa). In J. C. Senna Martinez, A. C. Martins, A. Ávila de Melo, A. Caessa, A. Marques, & I. Cameira (Eds.), *Diz-me o que comes… alimentação antes e depois da cidade*. ACDPRINT, S.A.

Valente, M. J., & Martins, S. (2015). Os moluscos marinhos Como recurso alimentar no garb al-Andalus dos sécs. XII-XIII: Os sítios de Cacela Velha (Vila Real de Santo António) e Castelo de Salir (Loulé). In I. Gutiérrez-Zugasti, D. Cuenca-Solana, & M. González-Morales (Eds.), *La Investigación Arqueomalacológica en la Península Ibérica: Nuevas Aportaciones* (pp. 199–211). Nadir Ediciones.

Waines, D. (1994). The culinary culture of Al-Andalus. In S. K. Jayyusi, & M. Marín (Eds.), *The Legacy of Muslim Spain* (pp. 725–740). Leiden, New York: E.J. Brill.

Welker, F., Hajdinjak, M., Talamo, S., Jaouen, K., Dannemann, M., David, F., Julien, M., Meyer, M., Kelso, J., Barnes, I., Brace, S., Kamminga, P., Fischer, R., Kessler, B. M., Stewart, J. R., Pääbo, S., Collins, M. J., & Hublin, J.-J. (2016). Palaeoproteomic evidence identifies archaic hominins associated with the Châtelperronian at the Grotte du Renne. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(40), 11162–11167.

Woolgar, C. (2003). "Take this penance now, and afterwards the fare will improve": Seafood and late medieval diet. In D. J. Starkey, C. Reid, & N. Ashcroft (Eds.), *England's sea fisheries: The commercial sea fisheries of England and Wales since 1300* (pp. 36–44). Chatham Publishing (Gerald Duckworth and Co Ltd).

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Toso, A., Schifano, S., Oxborough, C., McGrath, K., Spindler, L., Castro, A., Evangelista, L., Filipe, V., Gonçalves, M. J., Marques, A., Mendes da Silva, I., Santos, R., Valente, M. J., McCleery, I., & Alexander, M. (2021). Beyond faith: Biomolecular evidence for changing urban economies in multi-faith medieval Portugal. *American Journal of Physical Anthropology*, 1–15. https://doi.org/10.1002/ajpa.24343